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Editorial: Miniaturized Bioenergy and Energy Harvesting Systems

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Editorial on the Research Topic

Miniaturized Bioenergy and Energy Harvesting Systems

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Miniaturized energy harvesting systems, such as miniaturized microbial fuel cells, biological fuel cells, triboelectric energy harvesters, piezoelectric energy harvesters, represent an emerging area of research and have found a great potential for developing self-powered wireless sensor networks (WSN), Internet of Things (IoT), and portable electronics applications. Nowadays, power supply remains one of the major critical issues for the development of WSN and IoT. Semiconductor chips in the systems enjoy the scaling effect from miniaturization. The scaling effect means that when the size of devices is small, they have a higher surface area to volume ratio, smaller size, less expense, and faster frequency response. As a result, a variety of miniaturized sensors, actuators, and microsystems have taken advantage of the scaling effect, such as microprocessors, accelerometers, gyroscopes, micromirrors, actuators, biosensors, and resonators, etc. (Yazdi et al., 1998; Chae et al., 2005; Hu et al., 2010; Ren et al., 2011; Ren et al., 2013; Wang et al., 2014; Yeap et al., 2019; Fei and Ren, 2021). However, traditional power supplies, such as lithium-ion batteries, suffer from lower capacity due to miniaturization and often require frequent replacement after deployment. As a result, it is critical to develop miniaturized energy harvesting systems, which are self-sustainable, for these emerging applications.

Microbial fuel cells are bionic-based electrochemical fuel cells that directly convert the chemical energy stored in organic compounds from biomass into electrical energy (Logan and Rabaey, 2012; Ren et al., 2015; Ren et al., 2016a; Ren et al., 2016b). This is accomplished through the catalytic reaction of specific microorganisms called exoelectrogens or Anode-Respiring Bacteria (ARB) (Torres et al., 2008). Microbial fuel cell represents a carbon-neutral and renewable energy converter. Miniaturized MFCs have smaller chamber volumes compared with macro or mesoscale MFCs, and they are generally fabricated by microfabrication techniques. The surface area to volume ratio of miniaturized MFCs is high, resulting in a higher current and power density (Ren et al., 2012). Although the current and power densities significantly boosted in the past 2 decades, however, the current and power densities of miniaturized microbial fuel cells are still lower than conventional energy conversion and storage devices, such as lithium-ion batteries. The approaches which have the potential to further improve the current and power density of miniaturized microbial fuel cells are discussed in this topic by (Ren).

Biological fuel cells are fuel cells that convert chemical energy stored in organic compounds into electricity with the catalytic activity of biological enzymes or living entities. Compared with conventional energy conversion and storage devices, such as the lithium-ion battery, biological fuel cells can utilize the organic compounds in the environment and living entities, and it also represents a carbon-neutral and renewable energy converter (Li et al., 2020a). Miniaturized biological fuel cells utilize microfabrication and microfluidics techniques to reduce their size and they have the potential to be implemented into power sources for implantable medical devices. In this research topic, Maza et al. present a low-cost glucose/O_2 Y-shaped microfluidic biofuel cell that was developed using a printed circuit board (Mashayekhi Mazar et al., 2021). They implemented a double-side tape based on the pressure-sensitive adhesive to fabricate the microfluidic channel for the microfluidic biofuel cell. The electrode was coated with a nanocomposite that consisted of reduced graphene oxide gold nanoparticles (AuNPs). Aspergillus niger glucose oxidase enzyme and Mytheliophthora thermophile laccase were used to modify the anodic and cathodic electrodes. A maximum power density of 36 $\mu W/cm^2$ and an open-circuit voltage of 0.5 V are reported at a flow rate of 50 μL/min.

Triboelectric energy harvesters, also named triboelectric nanogenerator (TENG), implement triboelectricity, which is static-electricity charges generated by contact and motion between surfaces. When two materials are brought into contact and separated, the electric charge separation and induction process occur, and electricity is generated. Since its invention in 2012 (Fan et al., 2012), triboelectric energy harvesters have found many applications in self-powered systems, such as wearable sensors (Wen et al., 2019), trajectory-tracking microsystems (Ba et al., 2021), magnetic sensors (Yang et al., 2012), chemical sensors (Huang et al., 2021), etc. In this research topic, Zhao and Zhu discuss the application of triboelectric nanogenerator in smart home and clothing applications (Zhao and Zhu). For smart home applications, triboelectric energy harvesters can be implemented for switch sensors for smart home lighting fixtures, pressure sensors for home floors, power supply for home security systems, etc. For clothing applications, triboelectric energy harvesters can be implemented for sensing the frequency and acceleration when integrated into shoe sole, absorbing static electricity on clothes and reducing the static electricity on clothes, and sensing gestures when integrated into smart gloves, etc.

Piezoelectric energy harvesters utilize the piezoelectric effect to convert mechanical energy into electrical energy. The piezoelectric effect arises when a strain is produced on piezoelectric materials. Positive and negative charges accumulate on the two opposite surfaces of the piezoelectric materials, respectively. If we connect a load between the two surfaces with opposite charges, current flows. Thus mechanical strain energy is converted into electrical energy. Nowadays, piezoelectric energy harvesters have been widely implemented for self-powered systems and IoT applications, such as vibration- or motion-powered sensing and transmitting systems (Li et al., 2020b), self-powered motion detection systems (Li et al., 2021), and self-powered wearable upper limb (Liu et al., 2021). In this research topic, Guo et al. presented a theoretical and experimental study of the vibration dynamics of a 3D-printed sandwich beam with an hourglass lattice truss core. It has a provided potential solution to explore the advantages of using sandwich beams for piezoelectric energy harvesting (Guo et al.).

In addition to the miniaturized energy harvesters, power management systems are also critical as the output power from the energy harvesters cannot be directly used to drive the loads. Power management electronics are necessary for energy harvesting systems. The power management circuits aim to convert the output of the energy harvesters to voltage levels which can be directly fed to load, such as wireless sensors or IoT devices. A variety of power management systems for microbial fuel cells, biological fuel cells, triboelectric energy harvesters, and piezoelectric energy harvesters have been reported (Liang and Liao, 2011; Zhang et al., 2014; Xu et al., 2017; Liang et al., 2018; Liang et al., 2019). Due to the advantage of self-powering, carbon-neutral, and renewable characteristics, the miniaturized bioenergy and energy harvesting systems integrated with power management circuits may provide solutions to powering billions of WSN or IoT systems in the future.

AUTHOR CONTRIBUTIONS

HR wrote the original editorial, JL, JF, and XZ revised the editorial.

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